Senior Thesis

Seasonal Variations in Ground Penetrating Radar Data from a Former Refinery Site in Northwestern Indiana

By

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Abstract

An initial environmental survey of an Energy Cooperative, Inc refinery revealed that hydrocarbon contaminants are leaking into the subsurface and ground water. Ground penetrating radar surveys were conducted by Ohio State researchers on five separate occasions from July 1992 to May 1993. The information from three of these data sets were processed using Silicon Graphics workstations to detect the extent of variations due seasonal effects.

Introduction

The Environmental Resources Management-North Central, Inc. (ERM-North Central) conducted a preliminary environmental engineering survey of an Energy Cooperative, Inc. (ECI) refinery to evaluate the current and potential environmental hazards. The data collection process included: locating and inventorying tank contents, checking the status of process vessels and tanks, sampling and analyzing groundwater and soil, sampling and analyzing the water and sediment of the Indiana Harbor canal, and determining hydrocarbon and oil levels on the water table. The preliminary survey showed that the Indiana Harbor Canal sediments were contaminated with refinery and delivery systems waste. The source of contamination could not be definitely determined. In December of 1990, researchers from The Ohio State University began evaluating the land on either side of the canal using a ground penetrating radar system to detect hydrocarbon contaminants in the subsurface. Grids were laid out in three areas north of the canal, and two areas south of the canal. These grids were surveyed at five different times of the year beginning in July 1992 and ending in May 1993. The evaluation process of the ECI refinery began on July 11, 1984 when ERM-North Central was authorized by a United States District Court and the trustee to conduct the survey. The purpose was to identify environmental hazards and determine any immediate actions necessary to remedy primary risks or hazards to the environment. Following the evaluation, interim and long-term actions were to be proposed to reduce environmental problems associated with the refinery.

The refinery was built in 1919 and covers approximately 113 hectares. The facility was owned by Sinclair Oil from 1924 to 1968, when the Atlantic Richfield Company purchased the complex. In 1976, ECI bought the refinery and carried on operations until the company filed for bankruptcy in 1981. The following products have been produced at the site: mineral spirits, propane, unleaded and leaded gasoline, kerosene (jet fuel), asphalt and asphalt products, grease, lubricating oils, paraffin wax, phenol, and sulfur. Preliminary testing has shown that contaminants have entered the water and soils of the Lake George Canal that flows through the middle of the refinery site. The United States Environmental Protection Agency first filed a complaint against ECI I 1980 for twenty National Pollutant Discharge Elimination System permit violations. Preliminary investigations suggest an estimate of 15,160 gallons of oily waste floating on the water table beneath the site. The comprehensive assessment made by ERM-North Central estimated that 200 megaliters of hydrocarbon contaminants may be present on the area groundwater headed for the Lake George Canal. The concentrations of dibenzofuran contaminants was determined to be 7,000 ppb in on-site soil samples, 260,000 ppb in on-site groundwater and 155,000 ppb in surface water. The concern of contaminant seepage into the Lake George Canal prompted Ohio State researchers to survey areas on either side of the canal with a ground penetrating radar (GPR) system.

Location

The ECI site is located near the Coast of Lake Michigan in East Chicago, Indiana. The site is in Section 33 Township 37N Range 9W, which is about twenty-four kilometers northwest of Gary, Indiana. The refinery is situated on five parcels of land in the heavily industrialized refinery areas of East Chicago and Whiting (Skone 1991). The site is bordered by Indianapolis Boulevard to the east, Cline Avenue to the north, a high school and golf course to the south, and an Amoco oil refinery to the west.

Geologic Description

The primary geologic unit examined in the GPR project was the Holocene sediment within the upper three to five meters of the stratigraphic section. Eighteen three meter-deep well logs describe the lithologies of this unit. In general, the first five inches is a black, coarse, aromatic sand or a tan sand. This grades into a thick , grayish-black sand that carries a strong odor. The water table generally was struck at a depth of 1.2 to 1.8 meters. Well logs also indicate that 5 to 15 centimeters of oil were present on the water table.

Purpose

For the ECI project, the researchers used transmitting antennas with frequencies of 300 MHz and 80 MHz. Five grid patterns were laid out on either side of the canal and surveyed on five different occasions. These surveys took place from July 13-17, 1992, August 31-September 3, 1992, November 2-3,1992, February 24-25, 1993, and May 17-20, 1993. This thesis concentrates on data collected in the Southwest grid. The purpose of this paper is to determine the variations in data collected on the same grid at different times of the year. Data sets from September, November, and February were utilized for this purpose.

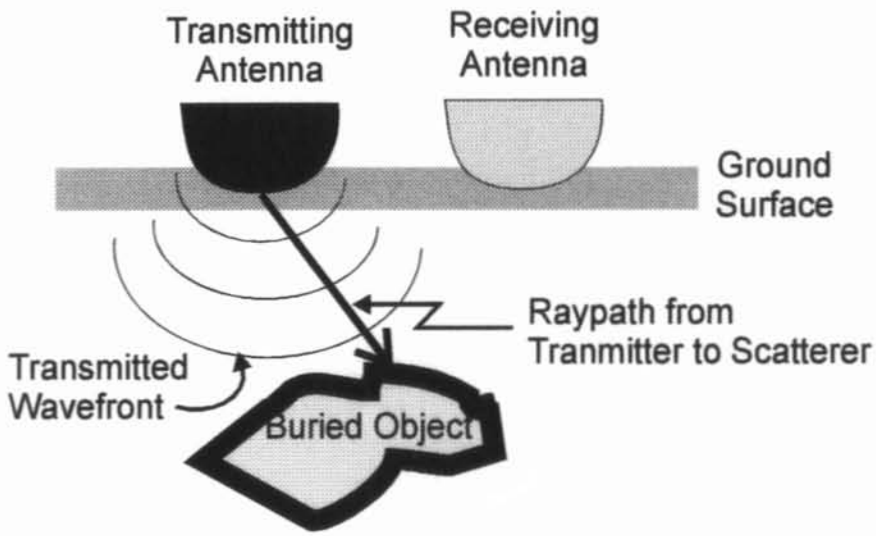
Ground Penetrating Radar Theory

GPR utilizes the reflection of electromagnetic waves to detect buried objects. The methods and theory of GPR are similar to those used in aircraft detection, although GPR antennas direct signals into the ground. A transmitter antenna sends an electromagnetic wave into the ground and the wave disperses until it encounters an object with electromagnetic properties that differ from the its surroundings (Figure 1). After striking such an object, part of the wave is reflected back up to a receiving antenna and is recorded on a digital storage device for future interpretation. The ECI data sets were collected using a continuous profiling method. This type of surveying uses a transmitting antenna that sends out a signal at fixed distance intervals (assuming a constant rate of motion is maintained). When the wave is transmitted, the receiver turns on for a specified time, and then shuts off. During the on time, the receiver collects the scattered energy from buried objects in the form of a trace. The on time for the receiver allows the depths of objects to be determined. Deeper objects have longer reflection times since the electromagnetic wave has farther to travel. The traces can be assembled to depict subsurface objects, (Figure 2) including hydrocarbon contaminant plumes. The ECI grids are made up of fifty-one parallel lines with a line spacing of two feet. The lines are two-hundred feet in length.

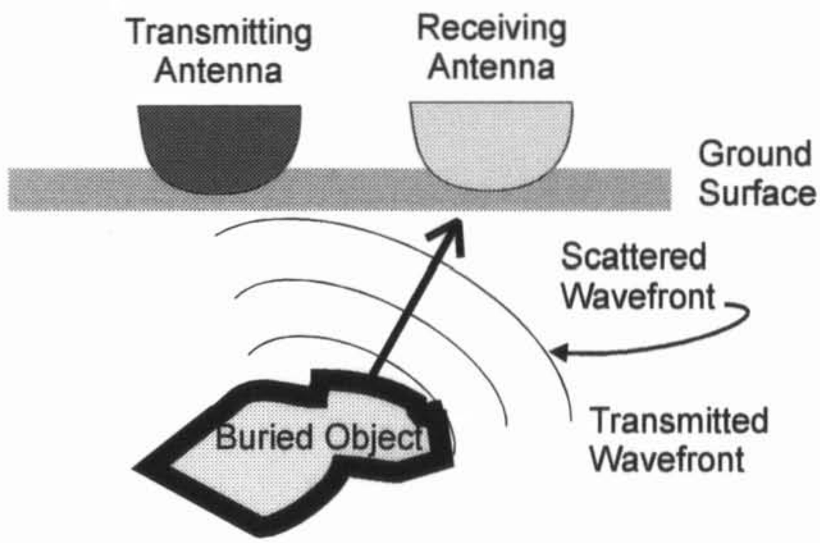
Data Processing

Although GPR data can be collected rapidly and in large quantities, the processing and interpretation of the data is complex and time consuming. Raw field data often needs to undergo several stages of processing before useful information can be extracted. Two dimensional cross sections, like those in figure 3, can be quite useful in determining depths at which different objects exist.

The data used in this thesis underwent the following processes: byte-swapping, line standardization, despiking, trace decimation, zero offset correcting, and one dimensional filtering. Figure 4 shows the which processes were used on each data set.



(a) Radar wave transmitted as a cylindrical
spreading wave.



(b) Scattered wave from a point on a buried object.

Figure 1. Reflection of a transmitted wave in GPR.
(Modified from Daniels 1996)

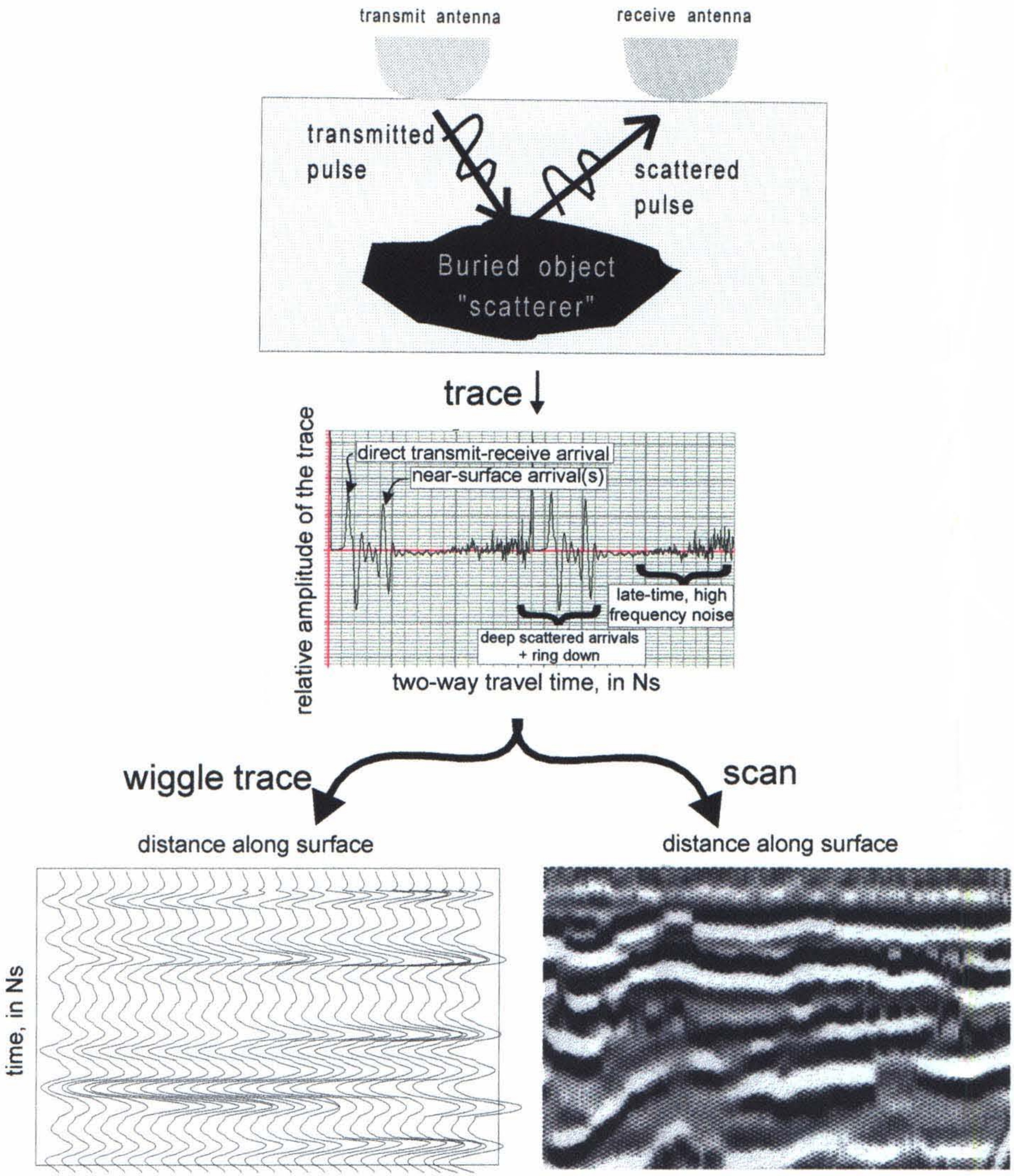


Figure 2. Steps involved in creating a GPR profile: 1. transmit and receive electromagnetic energy, 2. the received energy is recorded as a trace at a point on the surface, 3. traces are arranged side-by-side to produce a cross section of the earth recorded as the antennas are pulled along the surface. Traces are displayed as either wiggle trace, or scan plots (gray scale or color assigned to specific amplitudes). (Modified from Daniels 1996)

All of the above processes (except despiking can be performed using Radacal software written by David L. Grumman. The raw field data are read from tape archives (TAR's) and entered into the Radacal program. The first step is byte-swapping . This is a standard procedure for converting data collected on personal computers in the field into a form readable by Silicon Graphics machines. The swapping simply involves a rearrangement of bytes; the data itself remains unchanged. Following byte swapping, the lines need to be standardized. Line standardization adjusts all of the lines of a particular grid to a standard length. Extra traces are truncated and missing traces can be appended. Field problems such as slippage due to wet conditions can produce data lines that contain too many traces. Line standardization eliminates these problems. The direction in which lines are collected also becomes crucial in order to produce three dimensional images of the data. Line standardization allows line direction reversals to be done in the laboratory during processing. The 'despiking' process is used to remove noise from traces that was caused by the electronic data collection instruments. The basic algorithm that despiking programs use is to locate areas in a trace that have extremely high frequencies, and appear in a trace extraction as 'spikes'.

Trace decimation is used when the data's detail is greater than necessary. An example of a two dimensional cross section before and after trace decimation is shown in Figure 6. The decimation performed on the February data set involved removing every other sample within each trace. Hence, a trace that originally contained 1024 samples was reduced to 512 samples. Size reduction is very helpful in conserving computer space since one ECI line contains 1.5 megabytes of information. With fifty-one lines per grid and several stages of processing, a data set can easily consume 250 megabytes of memory. Hence, Silicon Graphics workstations are well-suited for this type of image processing.

The Radacal program also offers several types of filters. Band pass filters allow certain frequencies to be removed from the signal. The February data showed very low frequency noise that muddled the image. A band pass was performed on the data using a lower threshold of fifty Megahertz and an upper frequency limit of 750 Megahertz. This removed any signal that was below the low cut of 50 MHz and above the high cut of 750 MHz. Each data set requires the processor to carefully examine the data by looking at individual traces (like the one at the top of Figure 2) as well as two dimensional cross sections (provided in Appendices A, B, and C). There is no single filter that always improves images. Trial and error are required when using filters until one gains enough experience with GPR data.

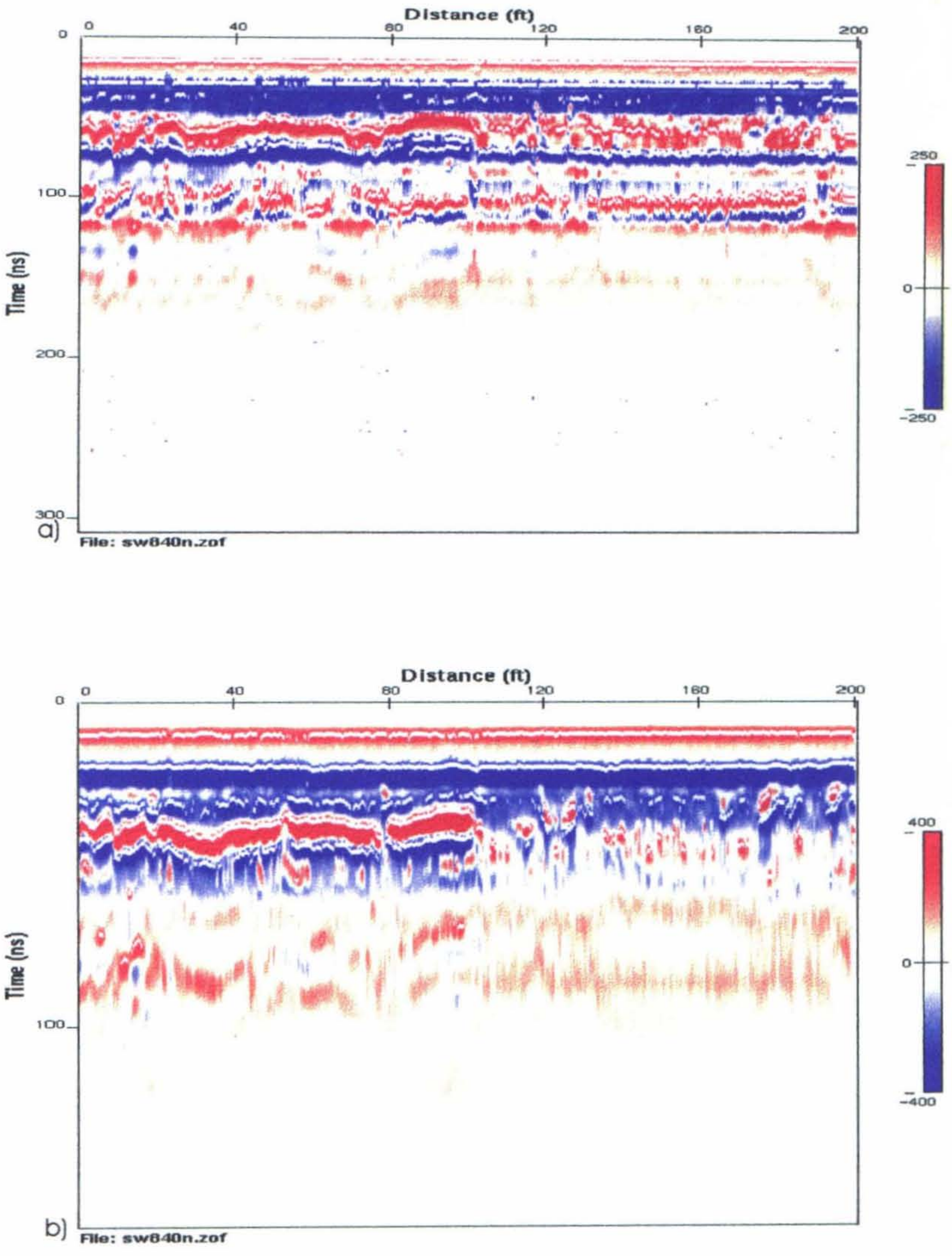


Figure 3. Comparing Line 40 for September and November.

Steps in Data Processing

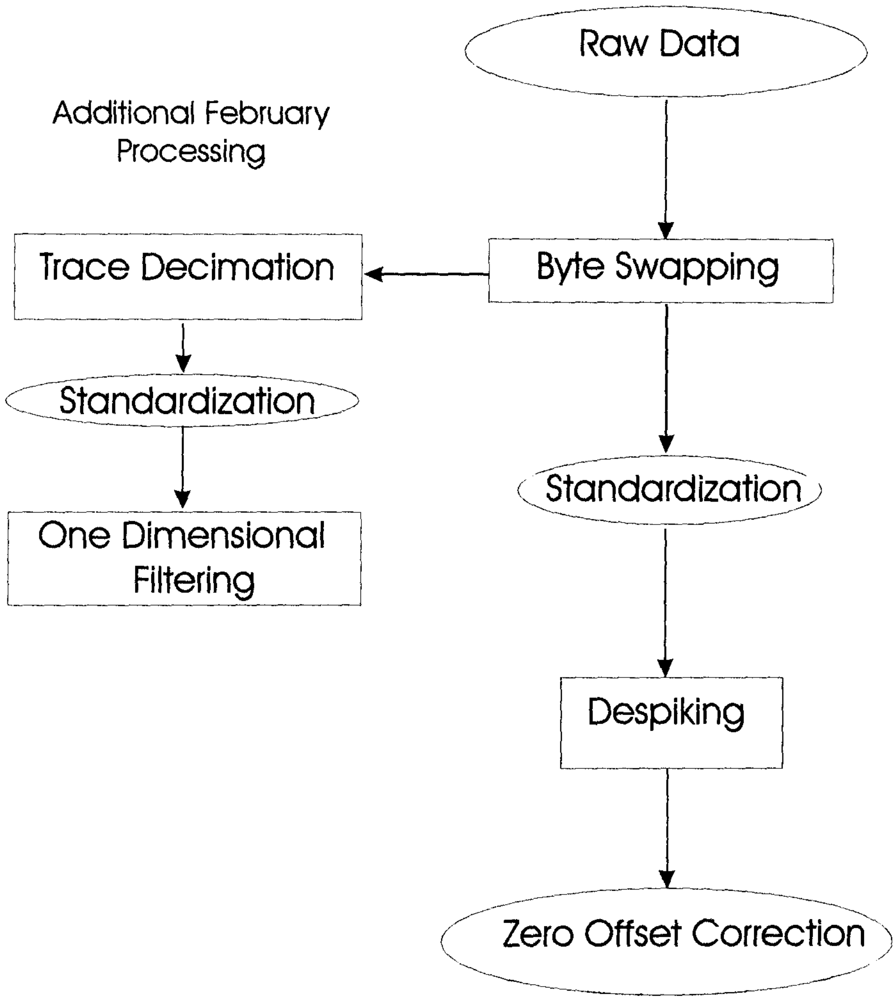


Figure 4. Data processing paths for February, September, and November data.

The zero offset correction process was used to compensate for a change in the zeroing of the instrumentation in the field during data collection. If the correction is not made, the arrival of the first reflection will appear to occur at different times and thus, different depths on cross sections. This can give the illusion of dipping subsurface features that are actually flat. The effect of zero offset correction can be seen in Figure 7, where a standardized, filtered, and zero offset corrected cross sections of the same line are compared. The zero offset correction ensures that all the two dimensional cross sections have the same zero. This is crucial for the creation of three dimensional images.

The dimensional processing is performed using the Brick of Bytes or BOB software package. All the prior steps in processing are carried out in order to prepare data for three dimensional imaging. The transformation from a group of two dimensional cross sections into a three dimensional image is shown in Figure 8. BOB files can show an entire grid of survey lines at one time. The BOB package is extremely useful because it allows rotation of the data block to a favorable viewing perspective. It also has the capability to 'look' at only specific depths or times. Hence, important features can be isolated and captured for hardcopy records.

Results

After processing the September, November, and February data sets as shown in Figure 4, the two dimensional cross sections revealed that seasonality does, indeed, affect ground penetrating radar data. Figure 5 shows the difference between data collected in September and November. The same grid line was used for the comparison, but different amplitude cutoffs were assigned to the color maps. One can see the difference that water saturation can cause in the data. The specified band, Layer A, is at the depth of a major storage tank at the ECI site. The breaks in the band in the November data may imply that the water saturation of pore space has an apparent affect on GPR data. The lack of a break in the identical survey line from only three months earlier is strong evidence that seasonal variations in rainfall and ground conditions can affect ground penetrating radar surveys.

Conclusions

The processing of GPR data from the Energy Cooperative, Inc. refinery site has revealed that seasonal variations do, in fact, influence the outcome of electromagnetic measurements, specifically ground penetrating radar. With further research, it may be possible to understand seasonal affects to the point of being able to take them into account for every survey. This will allow data sets to become more standardized and it will make comparisons more valid.

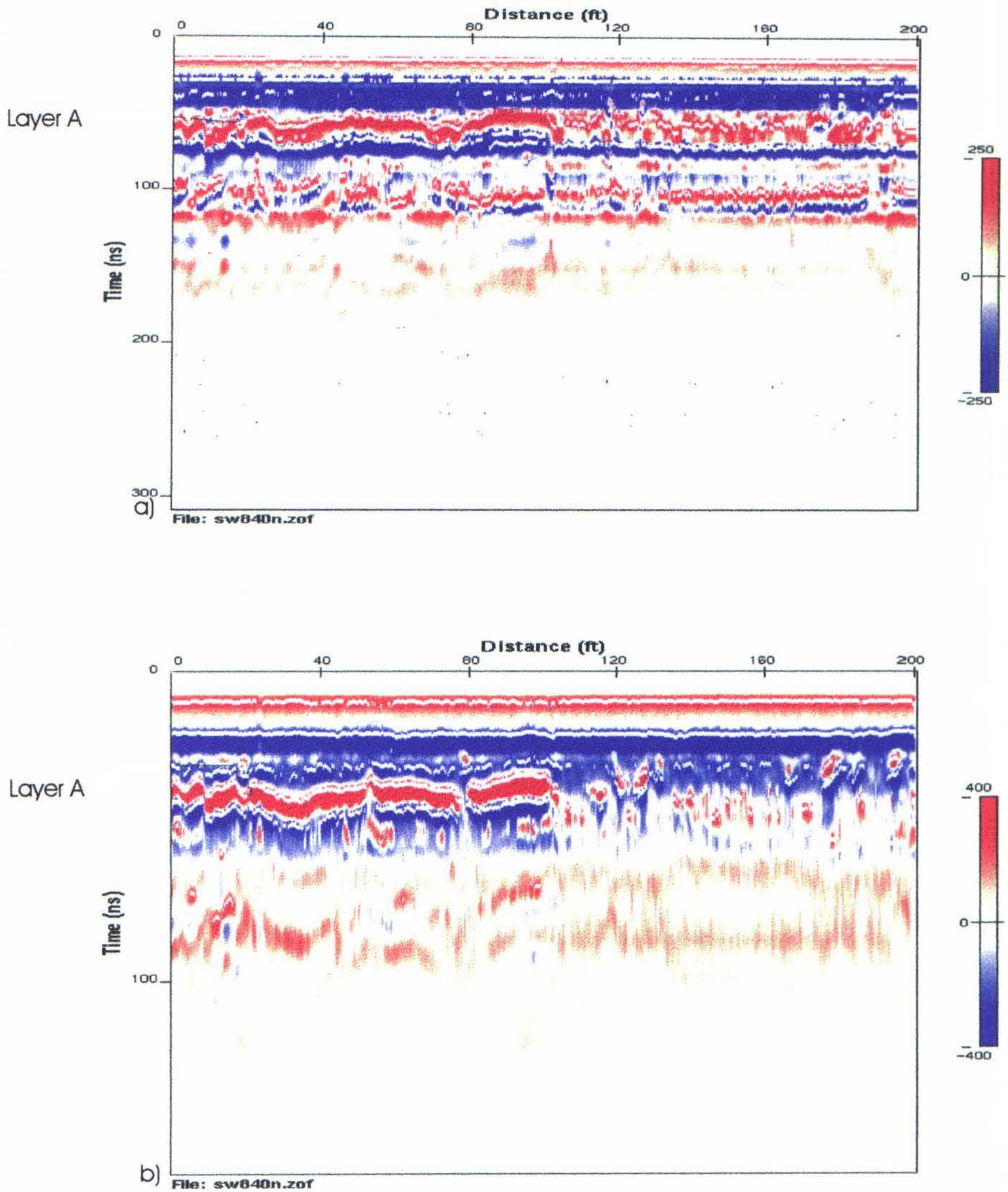


Figure 5. Comparing Line 40 for September and November. Layer A shows seosonal variation in data.

Trace Decimation

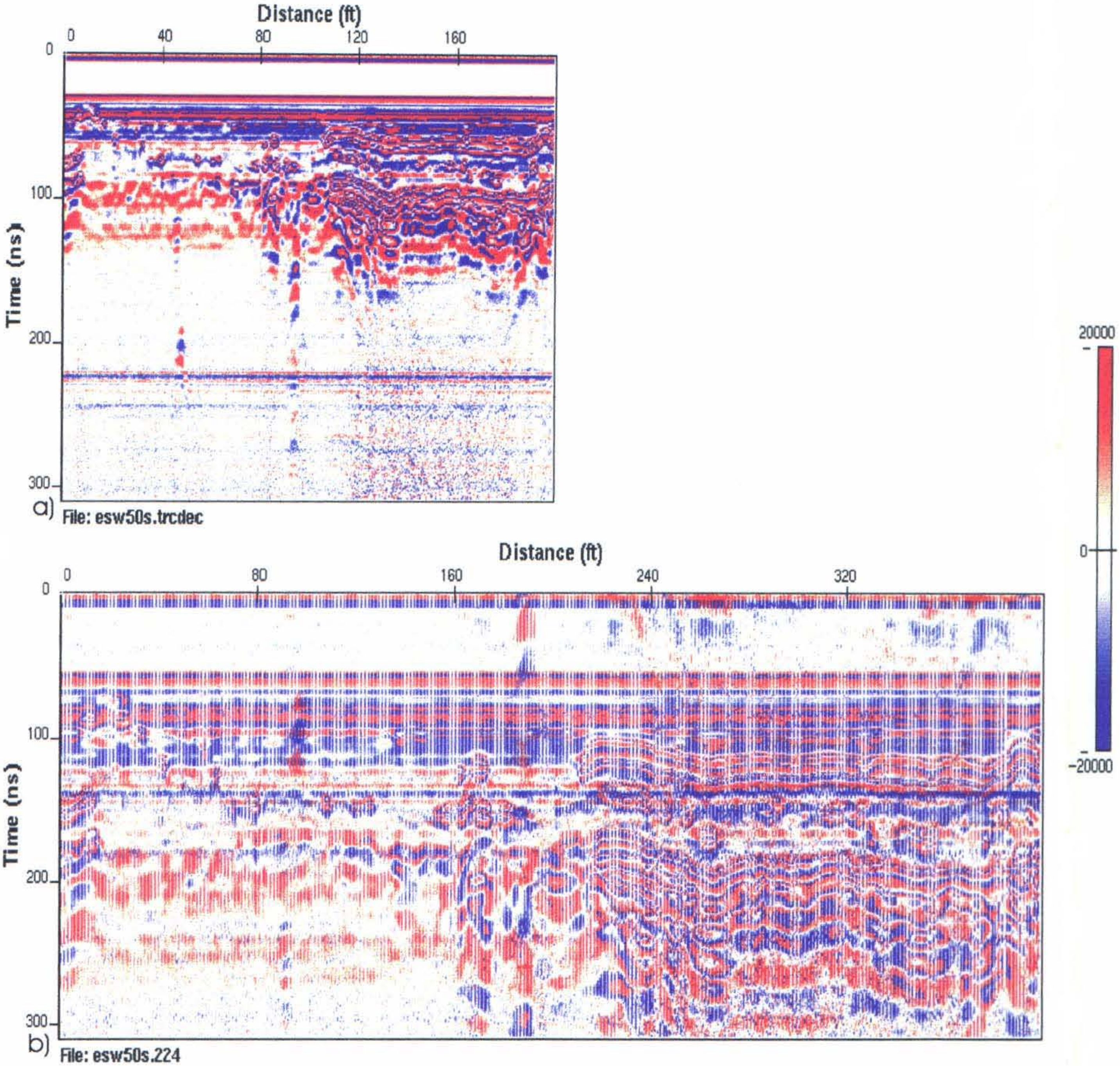


Figure 6. An example of a two dimensional cross section a) after trace trace decimation, and b) before.

Standardized, Filtered, and Zero Offset Correction Comparison

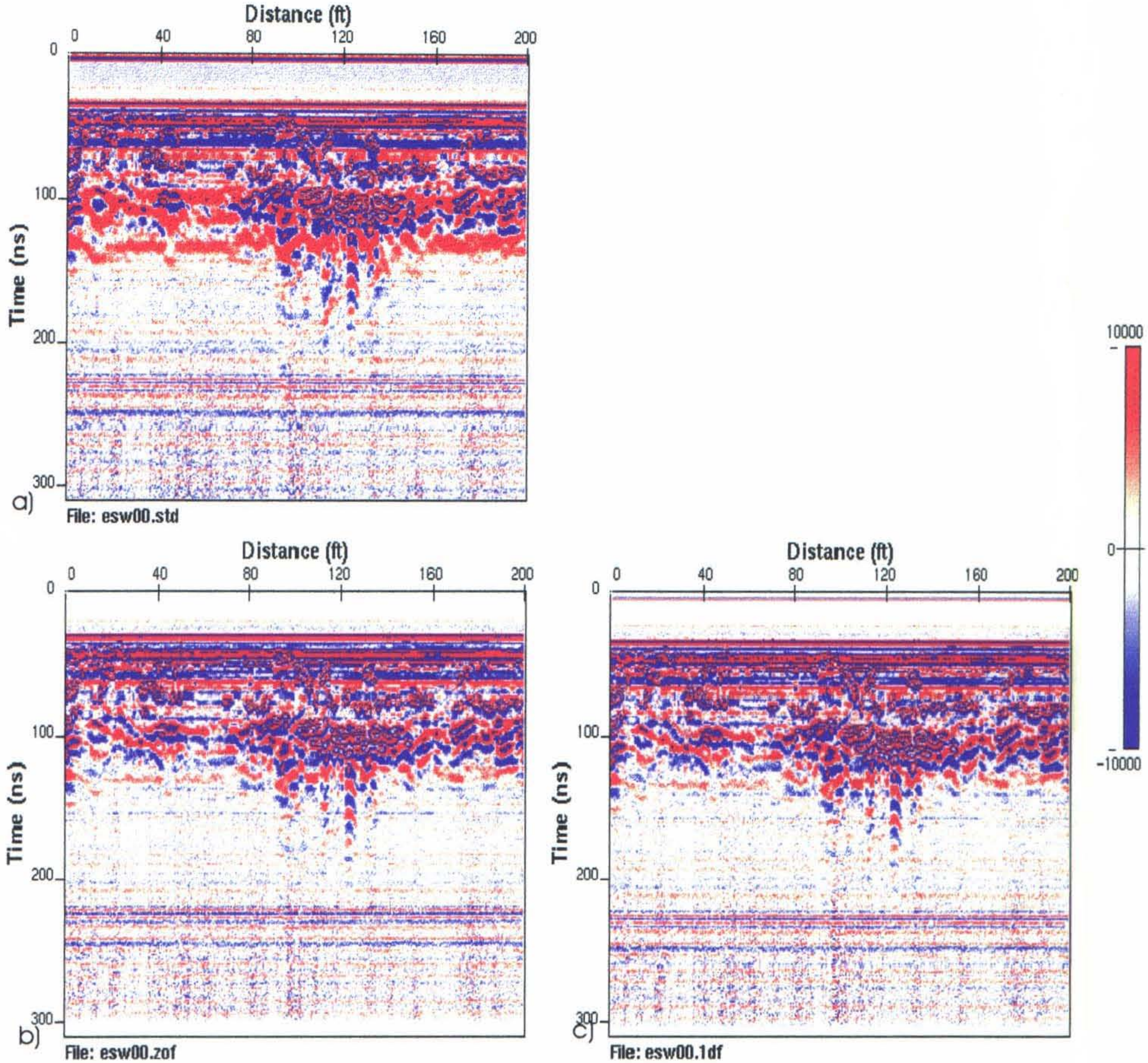
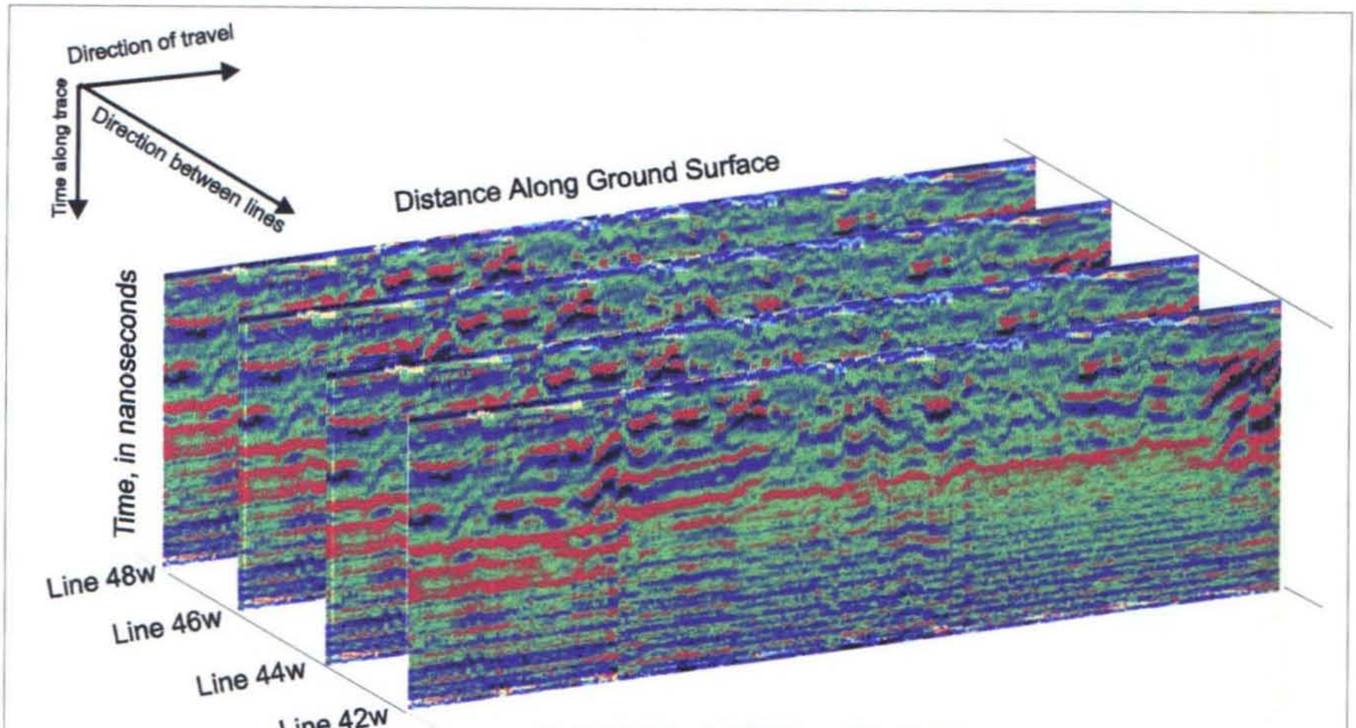
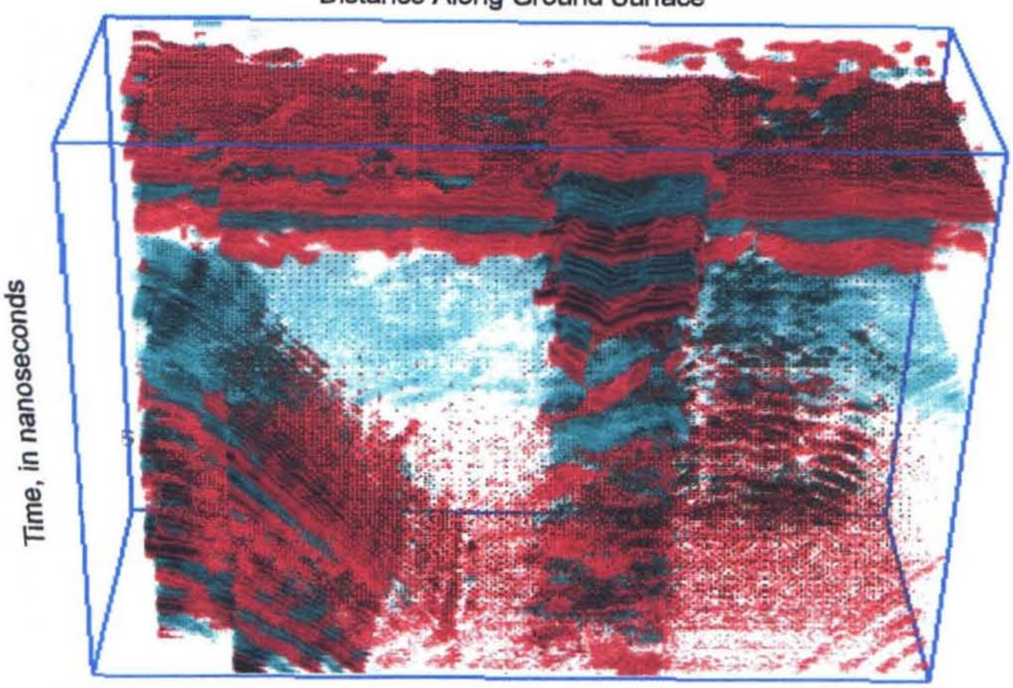


Figure 7. Comparison of a) standardized data with b) zero offset corrected data and c) one dimensionally filtered data.



a) Individual GPR profile lines



b) Schematic representation of vertical incidence GPR data using a **voxel - based display.**

Figure 8. Formation of three-dimensional display from two dimensional GPR cross sections. (a) Individual profile lines that comprise the three-dimensional display. (b) Three dimensional voxel (volume-pixel) - based display.(modified from Daniels 1996)

September 1992 Southwest Grid

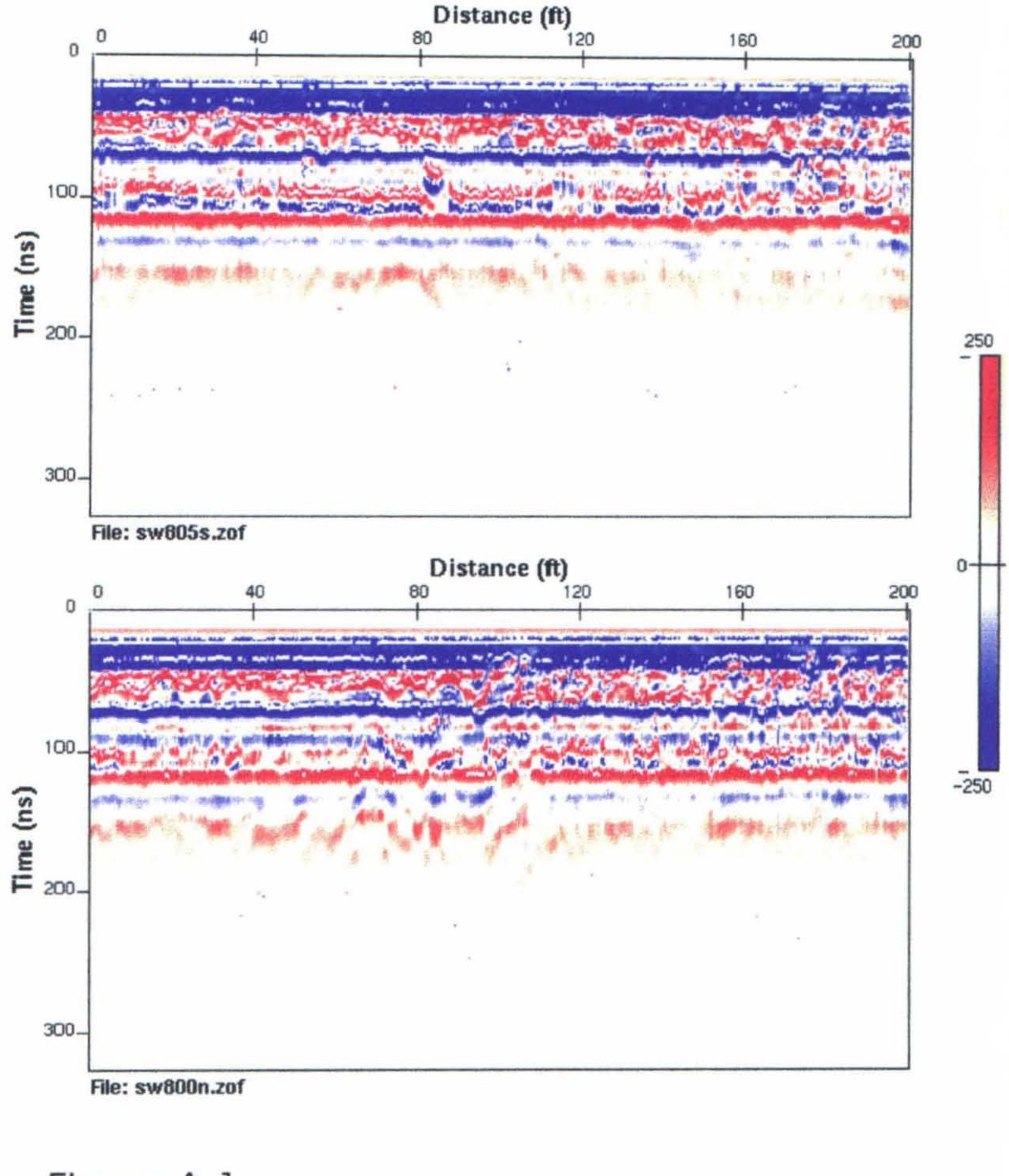


Figure A-1

September 1992 Southwest Grid

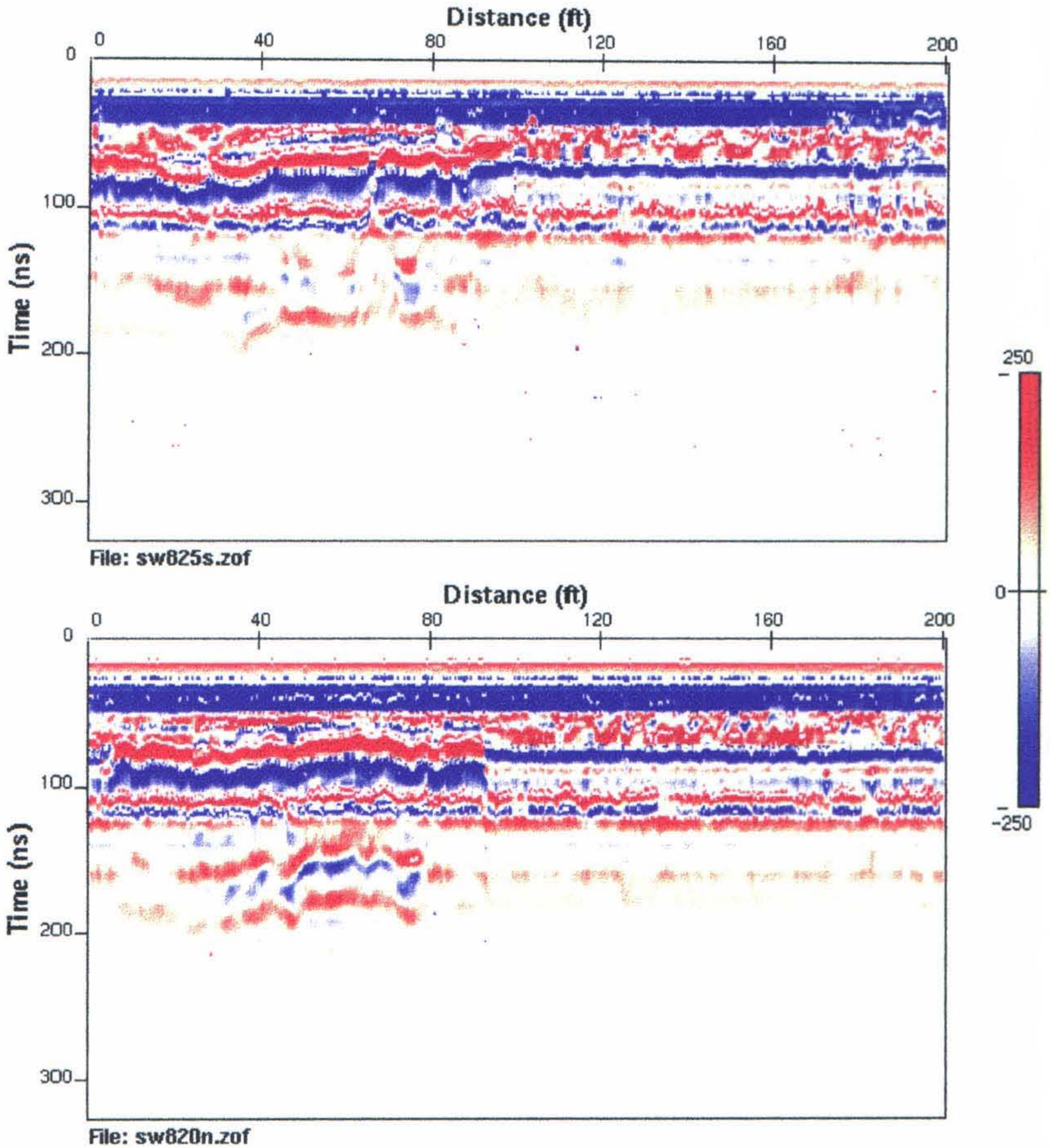


Figure A-2

September 1992 Southwest Grid

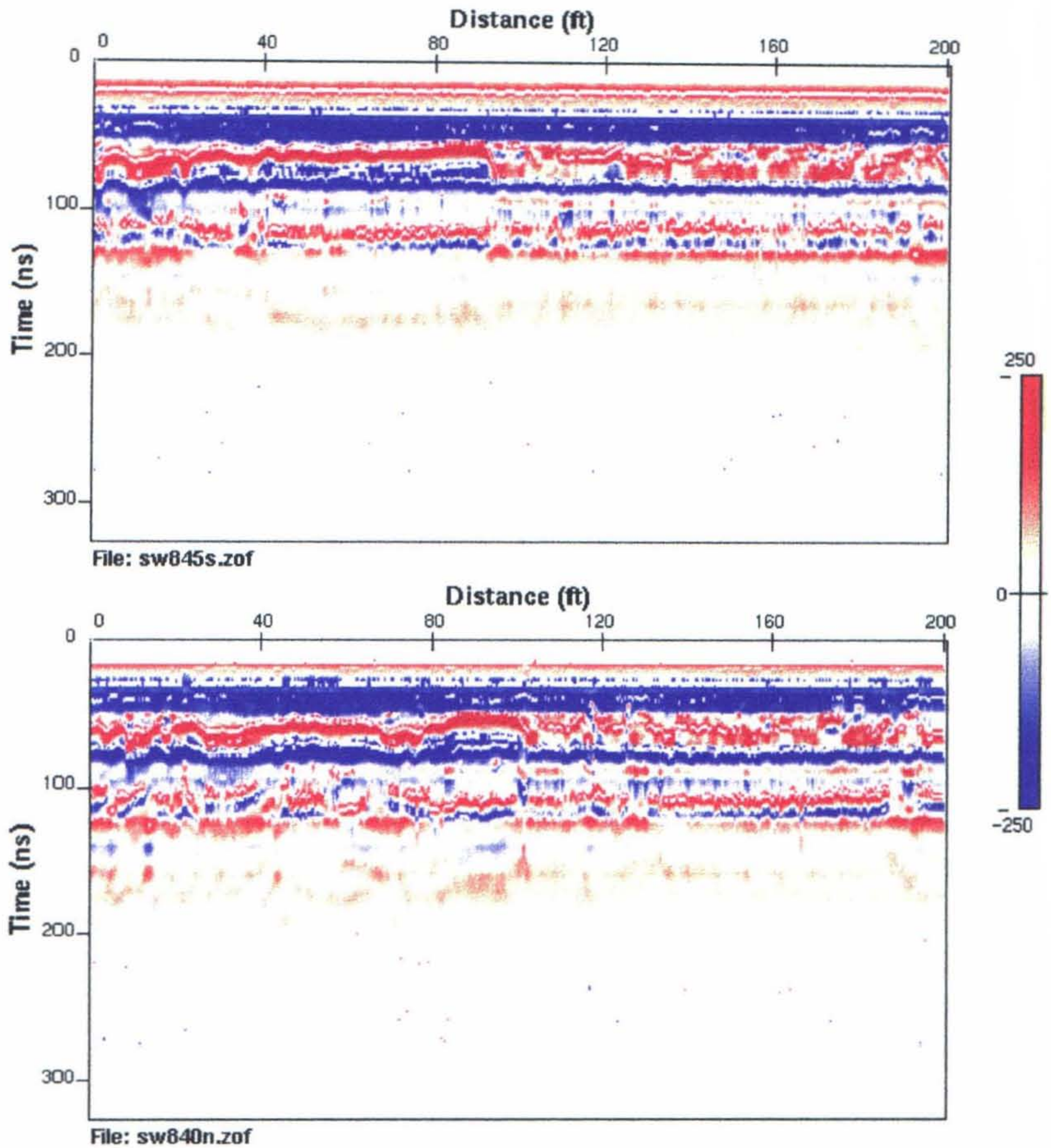


Figure A-3

November 1992 Southwest Grid

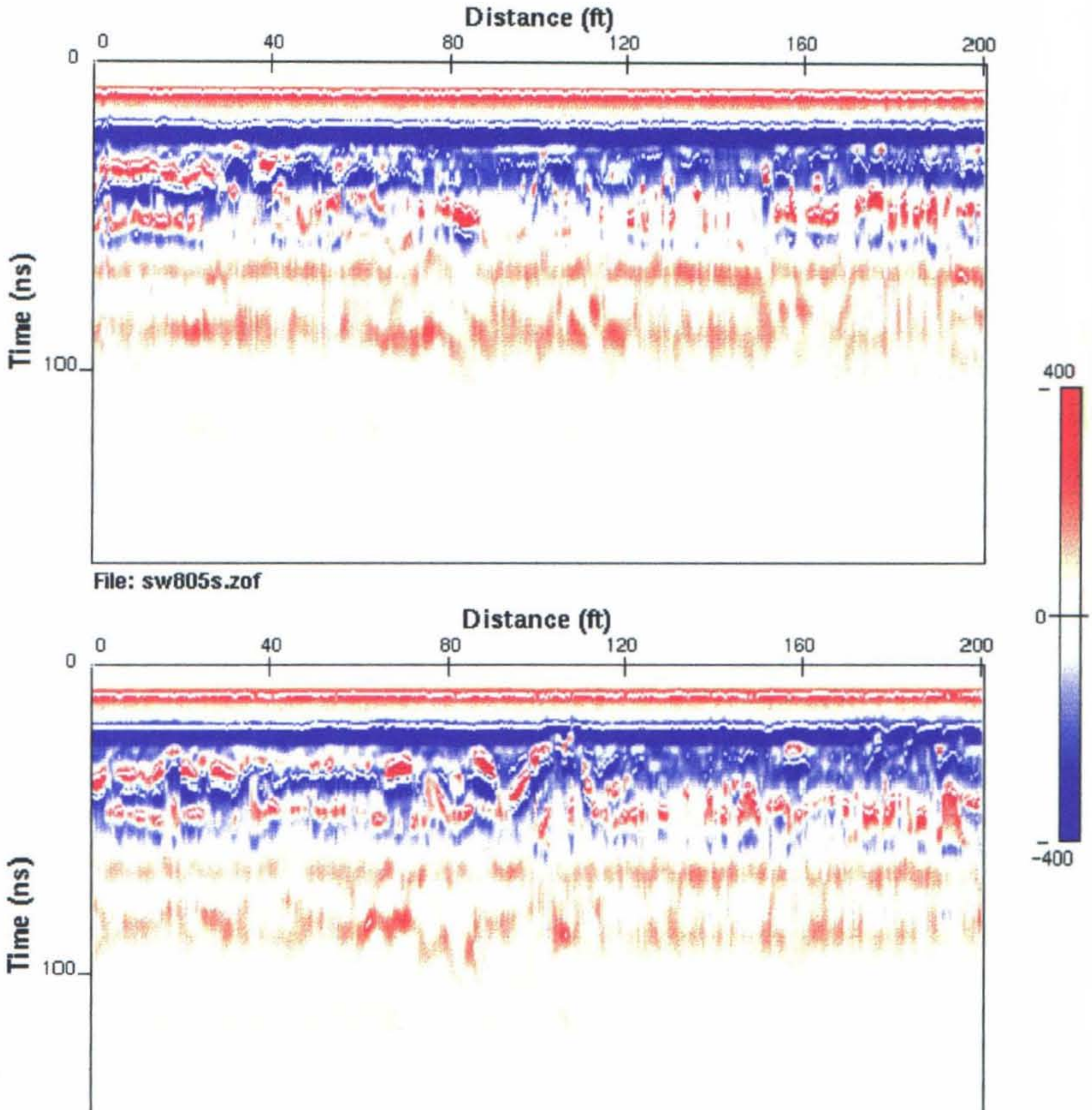


Figure B-1

November 1992 Southwest Grid

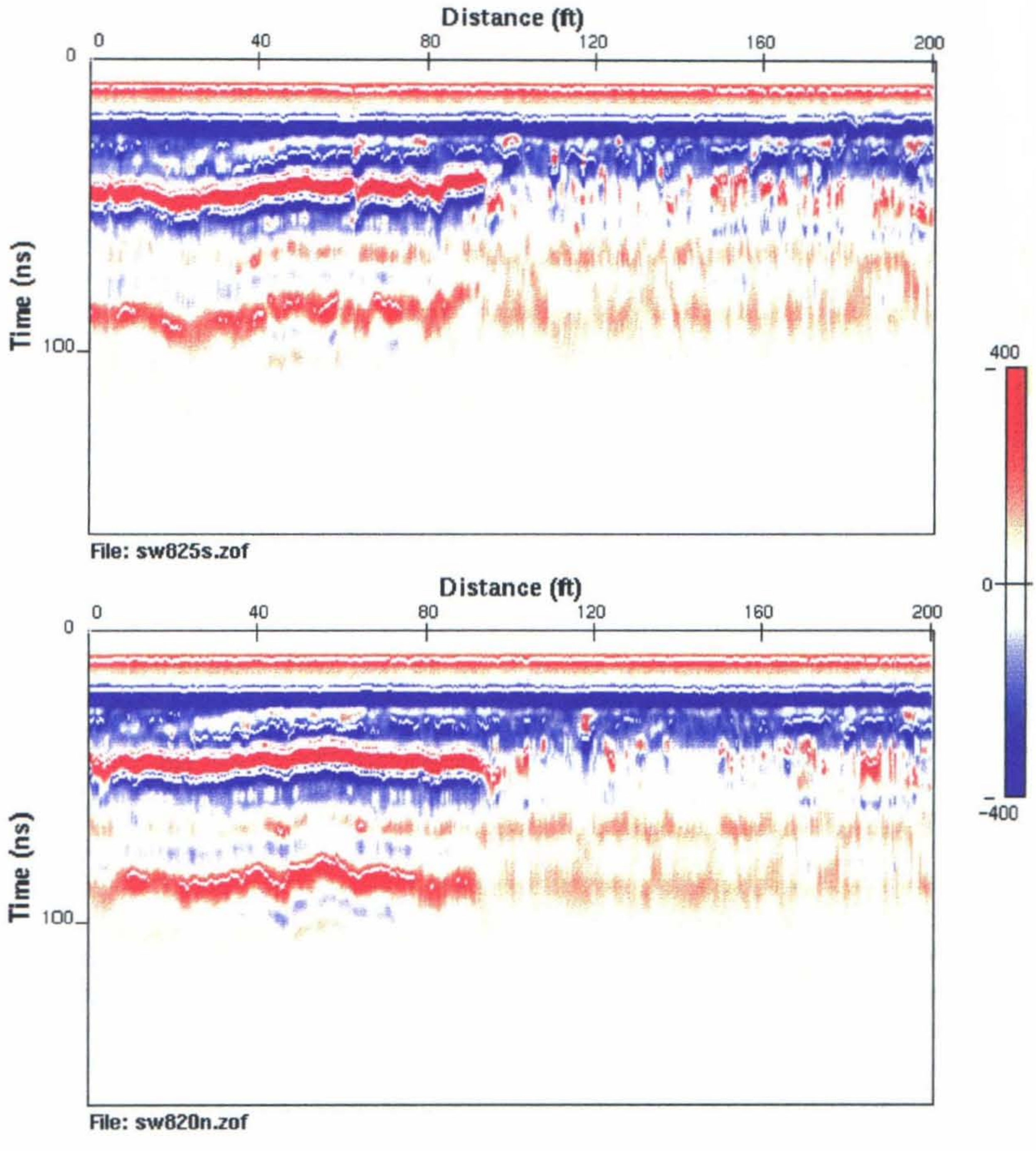


Figure B-2

November 1992 Southwest Grid

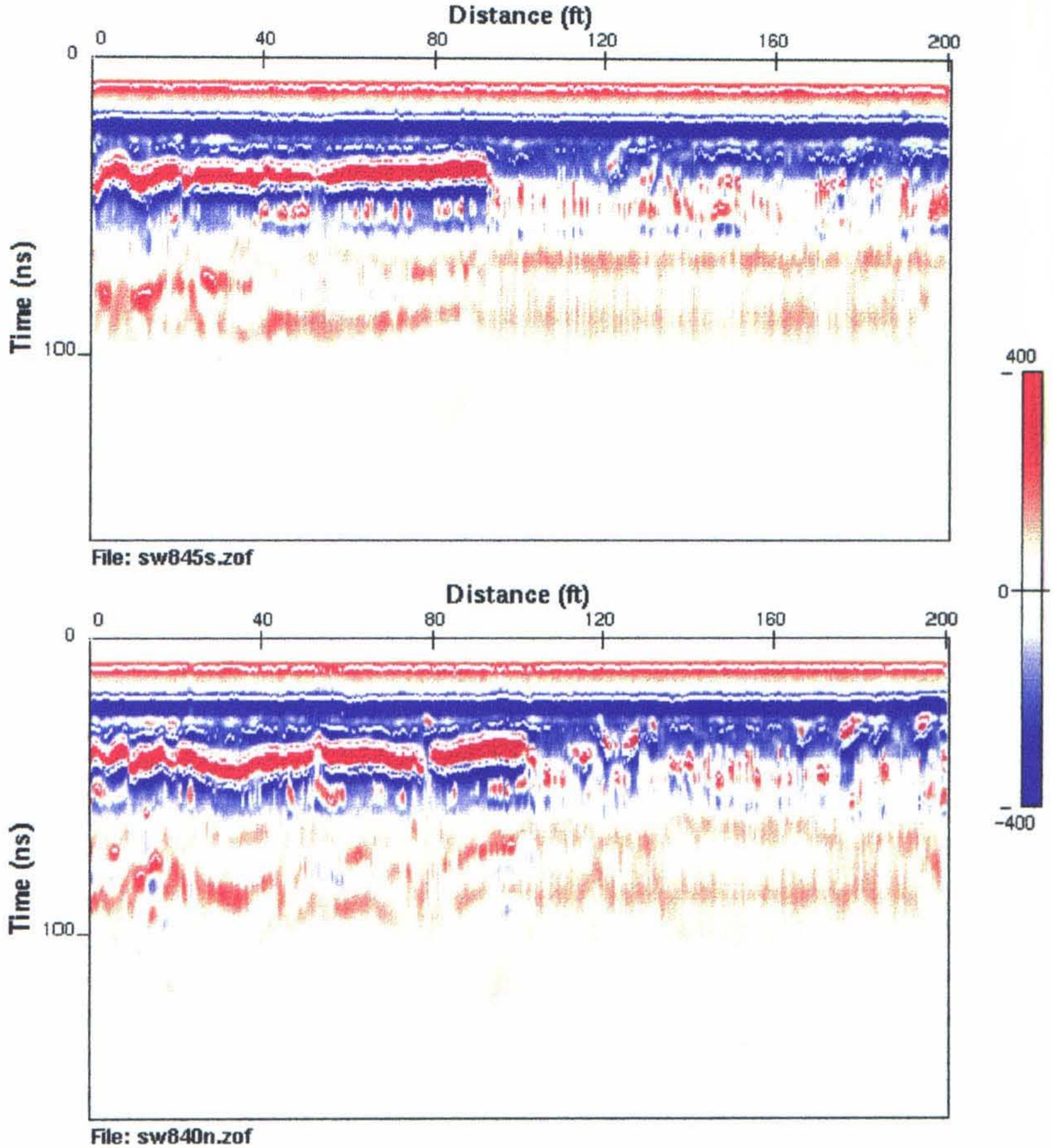


Figure B-3

February 1993 Southwest Grid

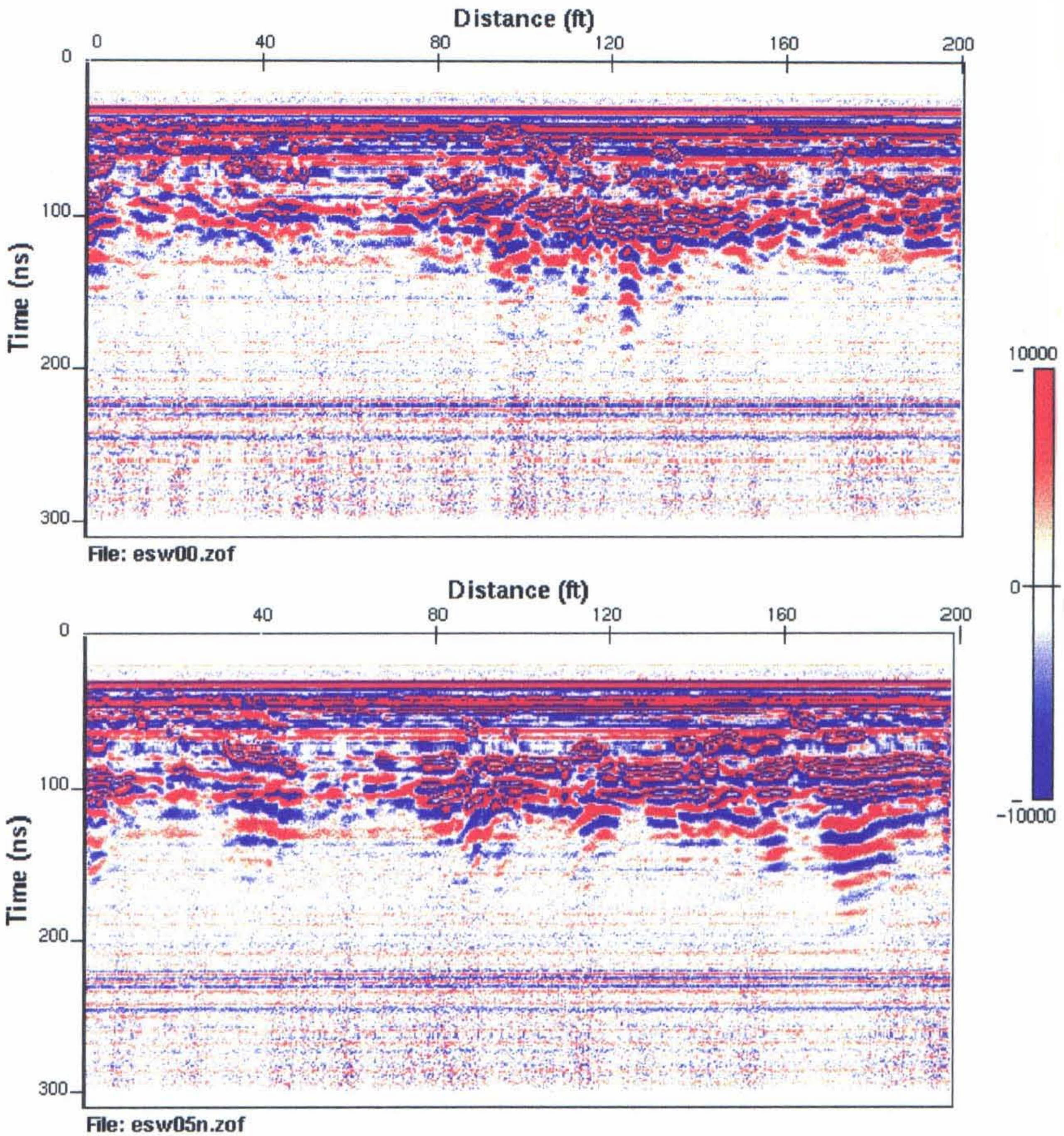


Figure C-1

February 1993 Southwest Grid

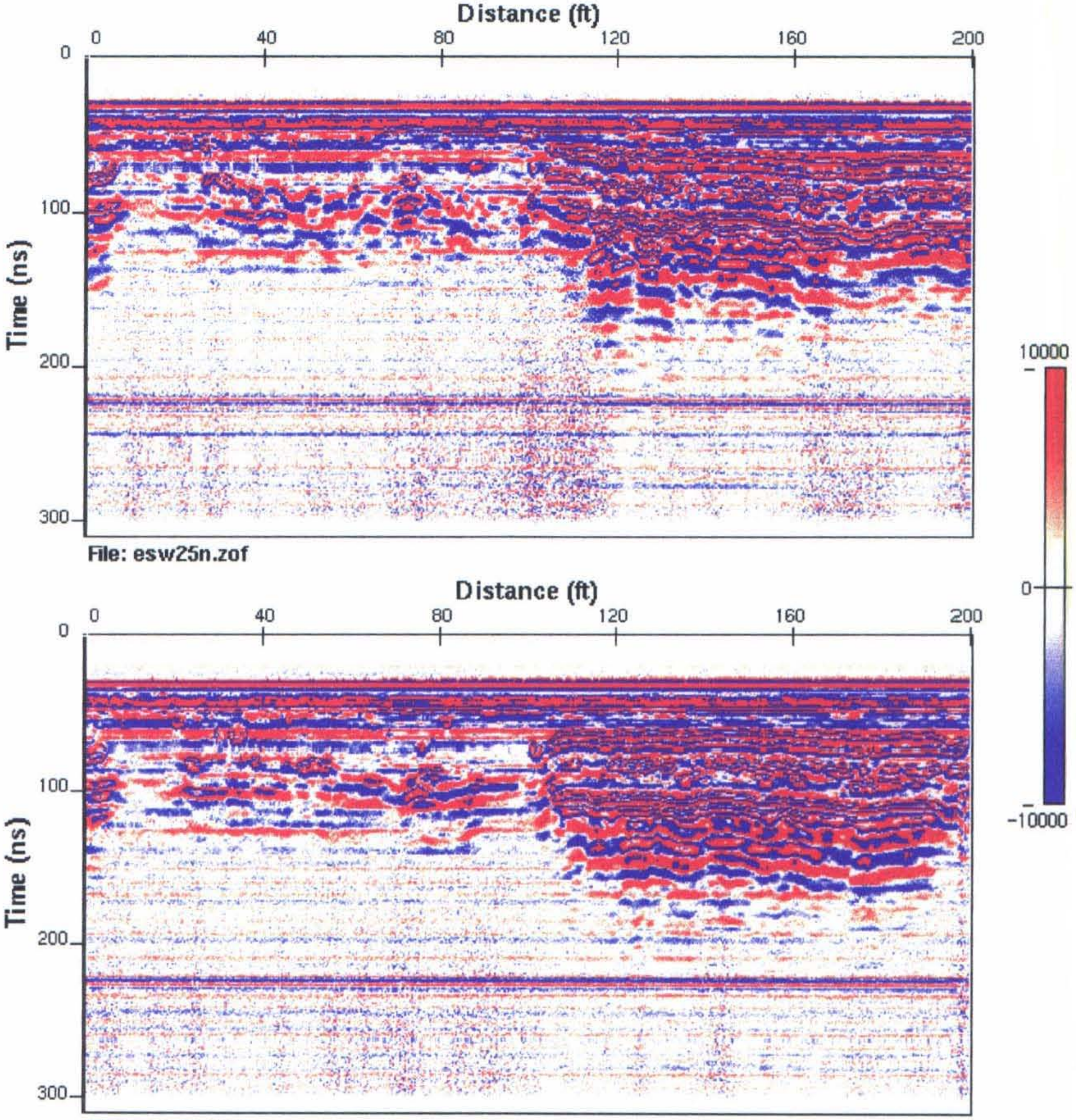


Figure C-2

February 1993 Southwest Grid

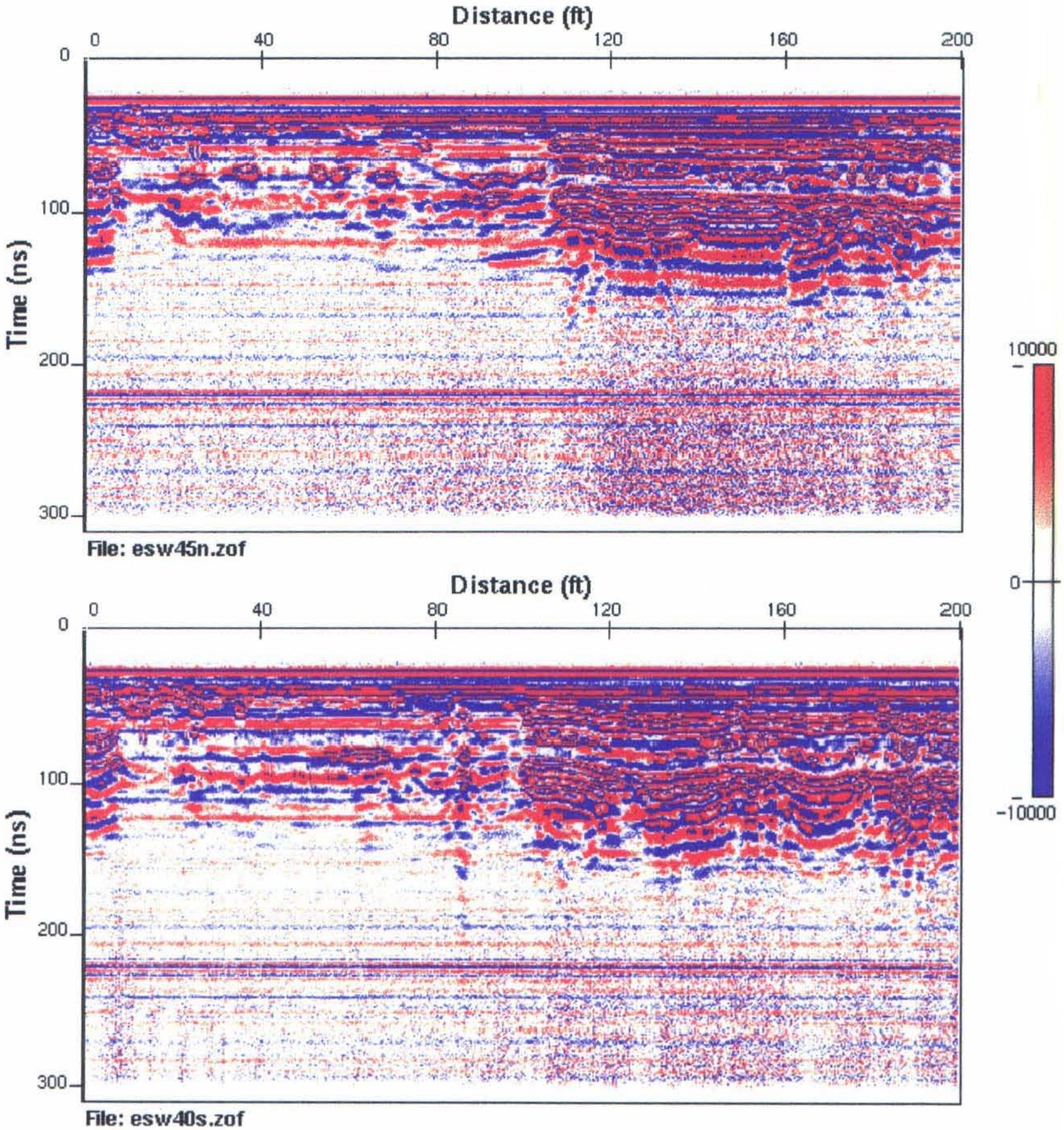


Figure C-3

References

Daniels, Jeffrey J, D.L. Grumman. Development of a Three Dimensional Subsurface Imaging Computer Display System for Using Ground Penetrating Radar to Locate Buried Substances. Columbus, Ohio, 1996.

Skone, Streven J. Removal Action Plan for Energy Cooperative, Inc. (ECI) East Chicago, Indiana: Chicago, Illinois, Ecology and Environment, Inc., pp. 24.